Propulsive Maneuver Design for the Mars Exploration Rover Mission

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Introduction

Starting from approximately 150 candidate Martian landing sites, two distinct sites have been selected for further investigation by sophisticated rovers. The two rovers, named "Spirit" and "Opportunity", begin the surface mission respectively at Gusev Crater and Meridiani Planum in January 2004. The rovers are essentially robotic geologists, sent on a mission to search for evidence in the rocks and soil pertaining to the historical presence of water and the ability to possibly sustain life. Before this scientific search can commence, precise trajectory targeting and control is necessary to achieve the entry requirements for the selected landing sites within the constraints of the flight system. The maneuver design challenge is to meet or exceed these requirements while maintaining the necessary design flexibility to accommodate additional project concerns. Opportunities to improve performance and reduce risk based on trajectory control characteristics are also evaluated.

Launch Vehicle Performance

Analysis of statistical ΔV requirements for both missions was primarily driven by the uncertainty associated with a single event: launch. The Spirit (MER-A) liftoff occurred on June 10, 2003 at 17:58:47 UTC with a 93 degree launch azimuth. The Opportunity (MER-B) liftoff occurred nearly a month later on July 8, 2003 at 03:18:15 UTC with a 99 degree launch azimuth. Navigation assessment of the launch vehicle performance at the Target Interface Point (TIP, defined as 10 minutes after Stage III ignition) and in the Mars targeting plane (B-plane) are well within expected deviations. The achieved orbital elements for the Spirit spacecraft are consistent to the 1-sigma level when compared to the target parameters. The same comparison is consistent to the 1.5-sigma level for the Opportunity spacecraft.

Trajectory Correction Maneuver (TCM) Strategy

The first trajectory correction maneuver for each mission was nominally scheduled for Launch + 10 days. However, analysis was performed to examine the TCM design characteristics from as early as Launch + 5 days extending all the way to Launch + 50 days. The objectives of TCM-1 were to remove the launch target bias necessary to accommodate planetary protection requirements, and also to remove launch vehicle injection errors. Numerous design considerations factor specifically into the TCM-1 analysis because of its large size. These factors include propellant cost, Sun angle power and thermal constraints, Earth angle telecommunication constraints, burn attitude, ΔV implementation mode, turn angle, and burn duration. TCM-A1, the first trajectory correction maneuver for the MER-A or Spirit mission, was further complicated by the desire to maintain flexibility in achievable landing site targets until the Opportunity spacecraft could retire the significant risk associated with its launch. Consequently, the arrival time target for TCM-A1 was selected for a central landing site between Gusev Crater and Meridiani Planum, which are on opposite sides of the planet Mars.

Final Approach Targeting Strategy

The final approach phase of the mission begins 45 days before entry into the Mars atmosphere. This phase includes two nominal maneuvers at Entry – 8 days (TCM-4) and Entry – 2 days (TCM-5). A final late contingency maneuver was placed at Entry – 4 hours (TCM-6). The intent behind TCM-6 is to

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utilize very late radiometric tracking that could identify a potential trajectory problem as the Martian gravity begins to influence the data.

The entry system is designed for a nominal inertial entry flight path angle of –11.5 degrees (at radius = 3522.2 km), but can accommodate a variation of ±0.75 degrees. Nominal TCM targeting controls three parameters at the defined entry radius: flight path angle, targeting plane orientation angle (equivalent to latitude), and time of entry. Trajectory sensitivity analysis at the time of the final approach TCMs shows a very high correlation between these target parameters. Consequently, the nominal targeting approach is unstable and extremely sensitive to minor modeling changes. This results in ΔV solutions much larger than pre-launch linear analysis would predict with undesirable effects on the surface path of the maneuver. A modified targeting approach was developed to utilize the robustness of the entry system and the high trajectory targeting correlations to control the desired surface target. This modified approach provides a direct surface correction path while reducing ΔV size, which also helps to improve targeting accuracy.

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References

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